Mathematics

DESIGNING A TRILATERAL FILTER TO DENOISE ANY IMAGE: HIT THE ROAD, NOISE.

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Noise can be systematically introduced into images during acquisition and transmission. A fundamental problem of image processing is to effectively remove noise from an image while keeping its features intact. The proper solution approach depends on the nature of the noise in the image. Two common noise models can adequately represent most noise added to images: additive Gaussian noise and impulse noise. Unfortunately, the best known methods for removing noise generally focus on only one of these models and perform poorly when applied to the other. We provide a universal filter that can automatically remove Gaussian noise, impulse noise, and any mix thereof. Further, the universal filter does not sacrifice ability for its versatility—in fact, it outperforms every other method we tested.

Additive Gaussian noise changes the value of each pixel in an image by a relatively small amount. Removing such noise requires smoothing inside the distinct regions of an image while preserving the sharpness of their edges. Classic linear filters, such as the Gaussian filter, smooth noise quickly and effectively. Unfortunately, their space-invariant design blurs edges too much. Recently, several spatially-variant, nonlinear methods have been proposed to remove Gaussian noise while leaving edges unaffected or even enhanced. Most notably, the anisotropic diffusion technique of Perona and Malik and the total variation approach of Rudin, Osher, and Fatemi have been widely studied. These methods use local measures of the image to quantitatively detect edges and smooth them less than the rest of the image.

In 1998 Tomasi and Manduchi introduced the bilateral filter as a new, intuitive approach for removing Gaussian noise. The filter is a simple windowed weighted average with a unique weighting function designed to keep edges intact while smoothing inside similar regions. Their method proved to be competitive with the established techniques mentioned above, although no theoretical foundation was found to explain its success. Recently, Michael Elad has bridged this theoretical gap in terms of minimizing functionals. The bilateral filter's main advantage is its ability to suppress noise quickly--it can effectively remove noise in a single pass that might take anisotropic diffusion and other PDE-based methods 50 iterations. It is also one of the simplest methods for smoothing inside image regions while keeping boundaries intact.

Impulse noise is characterized by changing a portion of an image's pixels to a random value, leaving the remaining pixels unchanged. Removing such noise ideally consists of replacing the noise pixels with estimated values while leaving the remaining pixels alone. Filters designed to remove Gaussian noise--including the bilateral filter--fail completely at this task. They interpret large impulses as edges and either retain or even enhance them. For this reason, a separate class of spatially-variant, nonlinear filters have been developed specifically for the removal of impulse noise; many are extensions of the median filter or otherwise use rank statistics. Median-based filters, however, are not designed for smoothing inside image regions and leave visually-disappointing results when applied to images with Gaussian noise.

Not much work has concentrated on the removal of both Gaussian and impulse noise. Peng and Lucke have suggested a fuzzy filter designed specifically for mixed noise. Additionally, in 1996 Abreu, *et al*., proposed the median-based SD-ROM filter to remove impulse noise, and their method proved very effective. In their exposition, the also give quantitative measures demonstrating the SD-ROM filter's ability to remove Gaussian and mixed Gaussian and impulse noise as well. While their filter has impressive quantitative results, it sometimes suffers the same disappointing output exhibited by other median-based filters when applied to images with Gaussian noise.

Using the bilateral filter as a base, we create a new “trilateral” filter capable of removing impulse noise while retaining the bilateral filter's ability to suppress Gaussian noise with visually pleasing results. Using multiple iterations, the new filter can also remove mixed impulse and Gaussian noise. With a weighting function based on a new image statistic, our trilateral filter can suppress very high levels of impulse noise with results superior to other established techniques. Only two additional parameters are introduced, the optimal value of which vary little across different images or different levels of noise. Further, our method does not require complicated training like many impulse noise removal techniques, and can therefore be expected to perform well with little effort.